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THE JURASSIC SEDIMENTS OF THE TYERS GROUP, GIPPSLAND, VICTORIA

By G. M. Philip

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Abstract

The Jurassic rocks of the Tyers Group comprise 2,000 ft. of sediments marginal to the main Jurassic basin in Gippsland. They are conglomerates, greywackes, sandstones (protoquartzites) and typical Jurassic felspathic sandstones with mudstones and minor coal seams present throughout the sequence. The normal felspathic sandstones of the Jurassic are regarded as arkoses rather than subgreywackes as has recently been suggested by Pettijohn (1957). Primary current features—cross-bedding measurements and pebble orientation studies within the conglomerates—together with matching rock types from the Tyers Conglomerate, indicate that the source of the basal part of the Tyers Group was the Siluro-Devonian greywackes to the north. The normal felspathic sandstones at the top of the sequence represent detritus brought in by current action derived from the same general source as the rest of the Jurassic. The conglomerates and the greywackes indicate rapid sedimentation whereas the sandstones (protoquartzites), which are "washed" greywackes, are the products of more stable sedimentation, an approach to that under which the felspathic sandstones of the Jurassic were deposited.

Introduction

The Jurassic sediments of Victoria are a widespread and uniform series. They are lacustrine sediments consisting characteristically of cross-bedded felspathic sandstones (arkoses) interbedded with mudstones. Grits and bituminous coal seams occur throughout the sequence to a much lesser degree while coarse conglomerates occur around the margins of the basin. The Jurassic sediments described in this paper contain the greatest known development of such conglomerates, although minor conglomerates mark the base of the sequence elsewhere (Edwards and Baker, 1943). Moreover, they contain sandstones distinctly different from the normal Jurassic "arkoses". They outcrop north of the Latrobe River in the Parishes of Tanjil East and Boola Boola and are here named the Tyers Group.

Murray (1876, 1887) first recorded the occurrence of Jurassic rocks in this part of Gippsland, and his original description is still the most complete. Whitelaw (1899), Easton (1908), Skeats (1935), Edwards and Baker (1943) and also Medwell (1954) have briefly mentioned the massive conglomerates which occur at the base of the sequence. Easton (1908) roughly mapped the boundaries of the Jurassic in this area, while Whitelaw (1926) published a coloured parish plan showing the geological boundaries in more detail within the Parish of Tanjil East.

The Tyers Group is well exposed along the valleys of Anderson's Creek, Tyers River, and Rintoul's Creek. It has a strike length of more than 14 miles with a regional dip of about 12° to the SSE. increasing to 20° in the east. To the north the Jurassic sediments unconformably overlie strongly-folded Siluro-Devonian greywackes, shales, conglomerates and limestones of the Walhalla "Series" and unnamed mudstone equivalents of the Tanjilian. The Tyers Group itself is unconformably overlain by Tertiary rocks. These consist of clays, then brown coals (exposed in Stony Creek) and quartzites overlain by Tertiary Older Volcanic basalt and the Latrobe Valley Coal Measures, which are in turn overlain by widespread sands and gravels, probably equivalents of the Haunted Hill Gravels of Thomas and Baragwanath (1949). The land surface on which these gravels were deposited appears to be sloping southward almost parallel to the present dissected land surface. Because of the extensive cover of Tertiary rocks good exposures are to be found only along river valleys.

To the west the Tyers Group is truncated by a fault. This is well exposed in road cuttings in the valley of a small east-flowing tributary of Anderson's Creek. Here the topmost beds of the Tyers Conglomerate dipping at 12° to the east can be seen directly abutting against almost vertical Siluro-Devonian mudstone. Thomas and Baragwanath (1949) have mapped a N.-S. trending fault about half a mile further westward called the Haunted Hill Fault. This fault is downthrown to the west in order to explain the difference in height between the brown coals and Palaeozoic sediments along the Latrobe River. In order to avoid possible confusion with this fault, the fault along the boundary of the Jurassic is here named the Anderson's Creek Fault. It is downthrown to the east with a displacement of over 1,000 ft. Where it is exposed near Anderson's Creek it trends almost N.-S. It is apparently a northward continuation of the Yallourn Monocline after it swings eastward. The Haunted Hill Gravels do not appear to be affected by it.

To the south the Tyers Group is truncated by the Yallourn Monocline, a structure which can be seen at the bridge across the Latrobe River at Yallourn and was well exposed in the excavations for the power station at Yallourn. Field indication of the monocline is best seen along the Tyers River where there is an increase in southerly dip of the Jurassic from 8° to 40° over a distance of less than half a mile. The complementary turn-up of the Latrobe Valley Coal Measures along the monocline can be seen at Yallourn North Open Cut. To the east the Jurassic again appears to be truncated by a continuation of the Yallourn Monocline, here trending NE. parallel to the present margins of the Latrobe valley. Lignitic clays and sandstones, apparently part of the Latrobe Valley Coal Measures, can be seen dipping eastward at 30° in the valley of Eaglehawk Creek where it leaves the foothills and flows out on to the flood plain of the Latrobe River. These sediments appear to lie within the monocline. Rocks similarly disposed were found still further north in the valley of the Thompson River in exploratory excavations down-stream from the Cowwarr diversion weir (Mr. Harding, personal communication).

South of the monocline, Jurassic rocks apparently underlie much of the Tertiary basin containing the Latrobe Valley Coal Measures. South of the Latrobe valley, Jurassic rocks again outcrop and comprise most of the South Gippsland highlands. (The Strzelecki Group of Medwell, 1954.)

Four measured sections were made through the Tyers Group along Stony Creek, Rintoul's Creek, the Tyers River and Anderson's Creek. These, together with a section compiled from field data collected at Yallourn North by Mr. F. Beavis of the Department of Geology, University of Melbourne, are summarized in Fig. 2.

Acknowledgements

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Classification of the Jurassic Sandstones

(A) Description

The normal basin sandstones of the Jurassic sequence of Victoria constitute a remarkably uniform rock type. The petrology of these sediments has been studied in detail by Edwards and Baker (1943). Briefly, the sandstones are characteristically medium-grained, and when fresh are greenish-grey, due to the presence of abundant chlorite cement. Where the rock is weathered the chlorite is oxidized to limonite and the rock is brown. In thin section the sandstones are seen to consist essentially of rounded to sub-angular igneous rock fragments, comparatively fresh felspars which are chiefly oligoclase with lesser amounts of orthoclase and angular quartz grains set in a chloritic cement (Pl. XXIX, fig. 1). Locally the cement is calcareous. There is little or no matrix. Micrometric analyses of several typical sandstones is given in Table 1.

Table 1

Micrometric Analyses of Typical Felspathic Sandstones of the Jurassic of Victoria

Constituents	1	2	3	4	5*
Rock fragments	43·6	41·8	44·9	37·3	44
Felspar	28·1	23·0	23·6	24·5	27
Quartz	10·1	14·6	13·0	9·8	10
Matrix	—	3·8	3·0	3·5	3
Cement†	17·7	16·0	15·3	20·6	15
Minor detrital minerals ..	0·5	0·8	0·2	4·3‡	1

* Approximate only as sandstone was weathered.
† Chlorite, zeolitic material and occasional partly-filled voids.
‡ Including 3·6 per cent carbonaceous material.

1. Griffith's Point, San Remo Peninsula.
2. Apollo Bay.
3. Lorne.
4. Tarra Valley, Gippsland.
5. Tcp of section, Anderson's Creek, North Yallourn.

The notable feature shown in this table is the high percentage of igneous rock fragments present in the sandstones, in places over 50 per cent of the detrital fraction of the rock. They all appear to be fragments of fine-grained to glassy andesite or andesite tuff.

Of particular interest also is the chloritic cement. This was regarded as a matrix by Richards (1909), but its true nature as an introduced chemical cement cannot be in doubt. It can be well seen in Plate XXIX, fig. 1, where it fills the spaces between the grains. In this particular sandstone from Griffith's Point, San Remo, the grains have been first overgrown or cemented by a thin film of what is either authigenic albite or a zeolitic mineral. Some of the spaces between the grains have been only partially filled by chlorite and voids have been left. In these interstices the chlorite is acicular with the long axes of the crystals of chlorite normal to the surface they encrust.

The origin of the chlorite is speculative. Edwards and Baker (1943) showed the mudstones associated with the sandstones to be rich in chloritic material, and concluded that the cement was introduced into the sandstones by connate waters associated with the mudstones. Chlorite cement in sandstones is uncommon. James (1954) has considered the large amounts of chlorite present in the iron formations of the Iron River and Crystal Falls districts of Michigan to be produced by the interaction of iron-rich sea-water and the finer fraction of the clastic material. However the chlorite cement of the Jurassic sandstones cannot be regarded as the reconstitution during diagenesis of a pre-existing matrix as some evidence of this would be seen in thin section. The widespread and uniform character of the cement does suggest that the source of the cement was within the Jurassic. Also, as the porosity of the rock is severely reduced by the presence of the cement, many local sources must be postulated rather than one main source.

(B) Classification

On the basis of Twenhofel's (1932, p. 229) definition of an arkose as a "sedimentary rock composed of material derived from the disintegration of acid igneous rocks of granular texture", Edwards and Baker classified the Jurassic sandstones as arkoses.

Most authors have followed closely the original definition of an arkose given by Brongniart (1826) as a sedimentary rock "composed essentially of large grains of glassy quartz and grains of lamellar, compact or clayey felspar: these two minerals are often mixed in more or less equal quantities but more often the quartz is dominant." (Oriel, 1949, p. 826.) No real agreement has been reached as to the composition of an arkose, but most authors are of the opinion that felspar should constitute more than 25 per cent of the rock (e.g. Allen 1936, Pettijohn 1949, Tallman 1949, Dapples, Krumbein and Sloss 1953, Krumbein and Sloss 1953, Carozzi 1953). Krynine (1940) set the lower limit of the felspar as being 30 per cent but later (1948) showed the average felspar content of his arkose series to be 25 per cent. Further, most authors have stressed the low percentage of detrital matrix and the presence of a chemical cement. As can be seen in Table 1 the Jurassic sandstones of Victoria have in general more than 25 per cent felspar in the detrital fraction of the rock (i.e. with the chlorite cement omitted). Thus they can be regarded as arkoses as defined above.

Recently Pettijohn (1954, 1957) has proposed a classification of sandstones which is among the first to provide an adequate conceptual framework for the naming of arenaceous sediments. Pettijohn has used provenance and maturity indices which are much more reliable than those of other authors in that the labile and stable constituents are not mixed in the derivation of those indices. According to Pettijohn (1954, 1957) an arkose is a sandstone with little or no detrital matrix, with or without a chemical cement and containing over 25 per cent labile constituents (i.e. rock fragments and felspar) of which the felspars are more abundant. From Table 1 it can be seen that within this definition the normal felspathic sandstones of the Jurassic cannot be regarded as arkoses as the rock fragments are present in greater quantities than the felspar. Moreover, Pettijohn (1957, p. 323) has suggested that the Jurassic sandstones as described by Edwards and Baker are greywackes or subgreywackes. The first possibility can be quickly discounted because of the almost complete lack of detrital matrix. It seems then that within Pettijohn's (1954, 1957) classification, the Jurassic sandstones should be regarded as subgreywackes, i.e. sandstones with little or no detrital matrix, with or without a chemical cement and containing over 25 per cent labile constituents of which the rock fragments are the more abundant.

This later definition conflicts with the original definition of a subgreywacke given by Pettijohn (1949). Here the subgreywacke as defined was virtually synonymous with Krynine's "low-rank greywacke" and Fischer's "quartzwacke" or "quartzmeng-wacke", sandstones which are products of a geosynclinal environment. In his later definition Pettijohn has attempted to define as a subgreywacke paralic "cyclothem" sandstones typified by the molasse of the Alps. This change in definition is confusing and not strictly permissible. The only way in which a universally accepted sedimentary rock classification can be maintained is by adhering rigidly to original definitions as Pettijohn (1943) has done for greywackes. Further confusion is likely to arise in that the term "subgreywacke" suggests a rock within the greywacke family, not a rock in origin related to arkoses. Clearly this leads to the possible confusion of greywackes with arkoses of which Krynine has stated, "the common mistake in the field of confusing arkoses . . . with greywackes . . . is sure to lead both to petrologic and interpretative disaster". (Krynine, quoted by Pettijohn, 1949, p. 260). For these reasons the author is of the opinion that the term "subgreywacke" should only be used as it was originally defined, synonymous with Krynine's "low-rank greywacke", the typical sandstones of a miogeosynclinal environment.

Because of the apparent inadequacy of the present compositional definitions of sandstones it is perhaps best to compare the examples which Pettijohn gives in illustration of his subgreywacke with the felspathic sandstones of Victoria to see whether they are truly analogous. Typically the subgreywacke of Pettijohn contains very little felspar. The Bradford Sand contains from traces to 1½ per cent and felspar nowhere exceeds 6 per cent of the rock (Krynine, 1940). The Oswego Sandstone contains from 3 to 5 per cent felspar (Krynine and Tuttle, 1941). The molasse itself usually contains very little felspar (Stiefel, 1957) but it may be present in appreciable quantities in places (Bersier, 1938). Rock fragments present may be up to 30 per cent of the rock, and are usually made up of sedimentaries or low-grade metamorphics, indicating that such a terrain constituted their source. Another feature is the high concentration of detrital chert in the rock which may be up to 30 per cent of the rock. This again indicates their derivation from a sedimentary terrain.

In contrast to this the Jurassic sandstones contain a considerable quantity of detrital felspar, enough for them to be regarded as arkoses by earlier definitions. The rock fragments are derived from a volcanic terrain and so are markedly different in character from those rock fragments of a subgreywacke. The difference in source rocks is also reflected in the virtual absence of detrital chert. Further it should be noted that the subgreywackes of Pettijohn (1954, 1957) are sandstones of a paralic environment, whereas the Jurassic has been deposited in a limnic environment (Edwards, Baker and Knight, 1944) which is more typical of arkoses.

An important morphological classification of sedimentary bodies was introduced by Krynine (1948). This classification is useful in distinguishing the various sedimentary associations as the shape of a sedimentary basin can be further correlated with its tectonic setting. For example, in general the orthoquartzite-carbonate association occurs mainly as "blanket" deposits in which the ratio of width to thickness of the deposit is over 1,000 to 1. The greywacke or "flysch" association occurs as tabular bodies in which the ratio of width to thickness is 50-1,000 to 1. Arkoses generally form prisms in which the width of the deposit is 5 to 50 times the thickness. The last category are the shoe-string bodies in which the width is under 5 times the thickness. Pettijohn (1957) states that the molasse or subgreywacke association (in his later sense) occurs typically as shoe-string sands.

This approach cannot be applied too rigorously to the Jurassic of Victoria as the margins of the basin are not accurately known. It is almost impossible to say whether there was a single large basin which has been broken up by later earth movements or a series of smaller basins. Because of the distinctive character of the andesite tuff fragments throughout the sandstones, Edwards and Baker (1943) have suggested a single large basin of deposition. On the basis of this they have suggested that the "basin appears to be a narrow trough, not less than 350 miles, and probably more than 450 miles, long, and in width somewhat in excess of 50 miles" (p. 224). In Gippsland the margins of the basin can be fairly well established. To the south at Chitt Creek, near Toora, Ferguson (1906) has recorded a thin conglomerate bed apparently at the base of the Jurassic, while the Tyers Group to the north undoubtedly represents a marginal facies of the basin. This suggests that here the width of the basin was of the order of 40 miles.

The thickness of the Jurassic is not known. Selwyn (1868) estimated the thickness as 5,000 ft. (quoted by Edwards and Baker, 1943), the same as the estimate made by Hunter and Ower (1914) on the basis of incomplete bore data.

This suggests that using Krynine's classification, the Jurassic approximates to being "prism shaped" or perhaps even "tabular". Most certainly they are not "shoestring", the typical manner in which subgreywackes occur.

A question which remains is whether or not, because of the high percentage of volcanic rock fragments, the sandstones should be regarded as tuffaceous sandstones. The rounded and weathered appearance of many of the fine-grained to glassy rock fragments suggests, however, that they were derived by the normal processes of erosion from a volcanic terrain rather than being directly consolidated primary volcanic ejecta. The rock thus cannot be said to conform to the definition of a tuffaceous sandstone as given by Wentworth and Williams (1932). Bailey (1926) on the other hand defined a tuffaceous sandstone as a sedimentary rock composed either wholly or in part of volcanic material which has been transported and redeposited by water, using the term in a sense similar to the "transport-tuffe" of Walther and Schirlitz (1886). The term "tuffaceous sandstone" should be confined to sandstones in which the primary eruptive origin of the volcanic material can be established. More recently Hay (1952) has suggested that sandstones rich in detritus derived from older volcanic rocks should be called "volcanic sandstones", although he still persists with the term "tuffaceous sandstones" for those in which the volcanic fragments are less than 50 per cent of the total detrital content of the rock. Adjectives such as "volcanic" and "metamorphic" are possibly of restricted use as source designations in the major sandstone grouping, but difficulty arises in their application (Pettijohn, 1954).

It is concluded that the felspathic sandstones of the Jurassic of Victoria conform more closely to arkoses than subgreywackes in that they contain over 25 per cent detrital felspar and little or no chert, they are the products of a limnic rather than paralic environment, and they form an approximately prism-shaped body. On the other hand they cannot be regarded as true arkoses as defined by Brongniart (1826) because of the very low percentage of quartz and the high percentage of rock fragments.

A very different approach from Pettijohn's is that of Folk (1954). In the classification of sandstones he would include all igneous rock fragments with felspar. On this basis the Jurassic sandstones may clearly be regarded as arkoses. For arkoses containing significant amounts of fragments of igneous rocks Folk has suggested the term "volcanic-bearing". The felspathic sandstones of Victoria are arenites of this type.

Sediments of the Tyers Group

(A) Tyers Conglomerate

This name has been applied to the conglomerates at the base of the series by Medwell (1954). Where they outcrop along the Tyers River they are a striking lithologic unit forming cliffs which rise over 400 ft. above the river level.

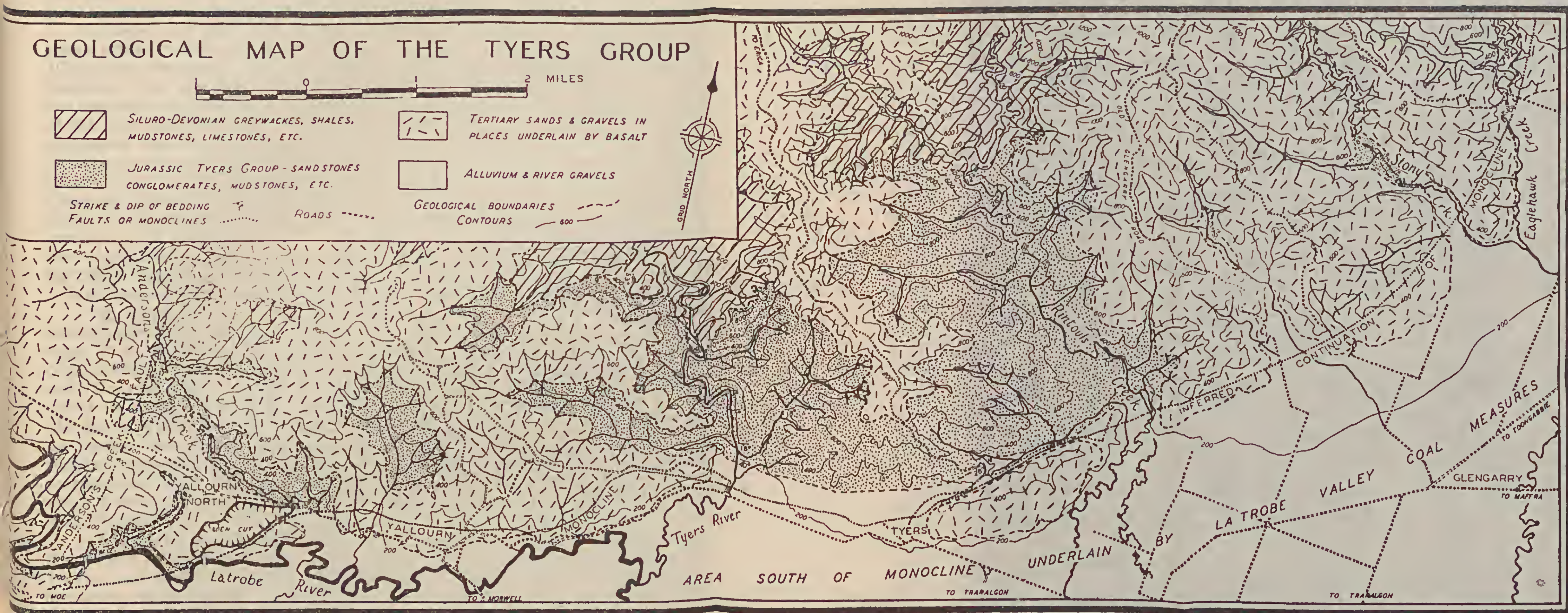
GEOLOGICAL MAP OF THE TYERS GROUP
0 1 2 MILES
SILURO-DEVONIAN GREYWACKES, SHALES, MUDSTONES, LIMESTONES, ETC.
TERTIARY SANDS & GRAVELS IN PLACES UNDERLAIN BY BASALT
JURASSIC TYERS GROUP - SANDSTONES CONGLOMERATES, MUDSTONES, ETC.
ALLUVIUM & RIVER GRAVELS
STRIKE & DIP OF BEDDING
FAULTS OR MONOCLINES
ROADS
GEOLOGICAL BOUNDARIES
CONTOURS
GRID NORTH
Stony Ck.
Eaglehawk Creek
MONOCLINE
CONTINUATION
INFERRED
LATROBE VALLEY COAL MEASURES
GLENGARRY
TO TOONGABBIE
TO MAFFRA
YALLOURN NORTH
OPEN CUT
YALLOURN
MONOCLINE
Tyers River
TYERS
Latrobe River
AREA SOUTH OF MONOCLINE UNDERLAIN BY LA TROBE VALLEY
TO MOE
TO MORWELL
TO TRARALGON
TO TRARALGON
TO ERICA

FIG. 1.

They consist of massive conglomerates with well-rounded cobbles of low sphericity. Occasional boulders, whose longest dimension is over one foot, occur throughout the exposures. Towards the top of the unit the cobbles become significantly smaller and many enter the pebble class (of the Wentworth-Udden size terms, i.e. between 64 and 4 mm.). Cross-bedded sandy intercalations are present within the conglomerate but here they are rarer than anywhere else. In places cement and matrix are virtually absent (Pl. XXX, fig. 3), and only a little unlithified sand occurs between the pebbles and cobbles. More usually and especially towards the top of the conglomerate it "is cemented with ferruginous and siliceous material" (Murray, 1876, p. 141). In general the conglomerate is buff in colour.

In composition the conglomerate is typically polymictic. An average of three rough pebble counts gives the composition as 73 per cent fine-grained greywacke, 10 per cent vein quartz, 6 per cent gritty greywacke, 4 per cent quartzite, 4 per cent mudstone, 3 per cent shale. Locally these percentages vary considerably. Vein quartz, the fragments of which tend to be subangular, often makes up an important fraction of the finer material in the conglomerate. These rock types, except for the gritty greywacke, can be matched perfectly with the rock types occurring in the Siluro-Devonian to the north. Low down in the sequence a fossiliferous pebble of the "Basal Conglomerate" of the Walhalla Series was recognized. To the west in Anderson's Creek the Siluro-Devonian sandstones immediately to the north and underlying the Tyers Conglomerate consist of pale-buff-coloured greywackes with a distinct concentration of detrital tourmaline. In this area cobbles of this rock form a significant part of the Tyers Conglomerate. North of the Jurassic contact along Stony Creek the Siluro-Devonian consists of an extensive series of soft highly contorted shales. It is perhaps for this reason that no conglomerates are found in the Jurassic there.

Away from the Tyers River the conglomerate loses its massive character and thicker softer sandstones are present in the sequence. Along Rintoul's Creek, in the upper 70 ft. of the formation, 50 ft. of non-conglomeratic sediments, which include cross-bedded creamy-buff sandstones with minor grits, grey and brown mudstones and a thin coal seam, are present. Grits and sandstones with minor amounts of mudstones are present elsewhere lower down in this sequence and in all constitute over half the total thickness of the formation. Along Anderson's Creek the proportions are similar. Here, also, as at the base of the conglomerate at Rintoul's Creek, the conglomerates tend to have a clayey matrix. In all other localities, however, the conglomerate has a highly siliceous cement. Overall, the conglomerates exposed along Rintoul's Creek and Anderson's Creek contain smaller cobbles than those of the Tyers River.

In length the Tyers Conglomerate is lenticular. At the cliffs along the Tyers River there is exposed a total thickness of about 390 ft. of massive conglomerate. To the west along Anderson's Creek, 178 ft. of conglomerate was present in a measured section. Further westward at Yallourn North the Tyers Conglomerate at the base of the section is only 30 ft. thick.

East of the Tyers River 335 ft. of conglomerate is present in the section along Rintoul's Creek, although, surprisingly, conglomerates are completely absent along Stony Creek where Jurassic sandstones directly overlie the Siluro-Devonian basement rocks. Further east at Eaglehawk Creek, beds of conglomerate up to 3 ft. thick are present in a very condensed section, in all totalling 66 ft. of exposed sediments.

The lensing towards the basin is more difficult to establish. It is best seen in a comparison between the section measured along the Tyers River where 237 ft. of conglomerate is present and the start of the section where there is 390 ft. of

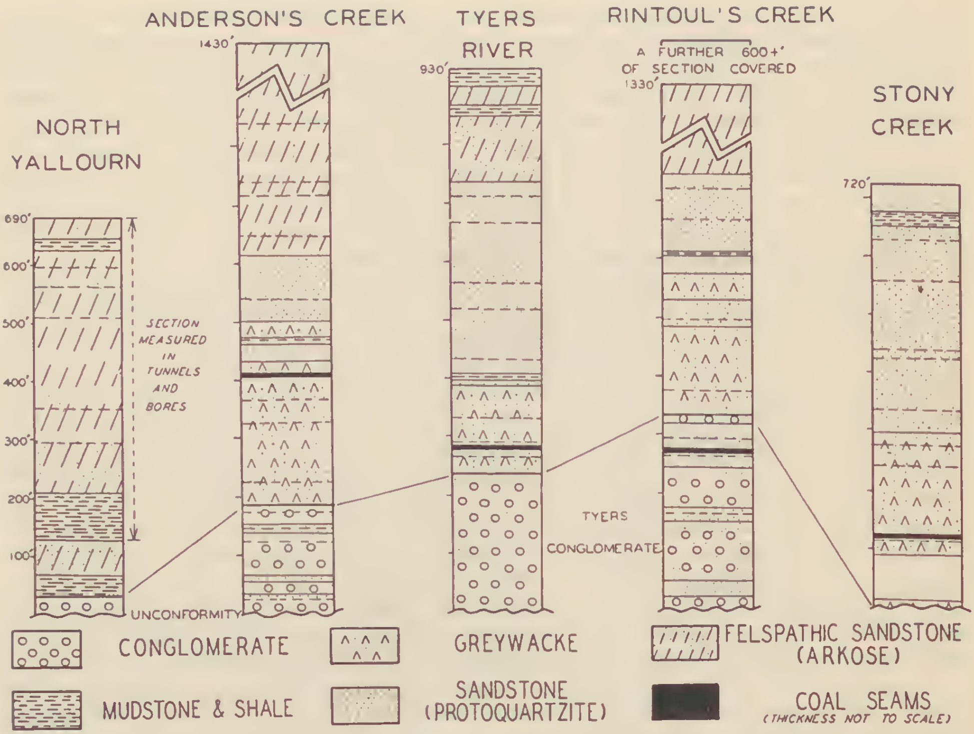

Fig. 2.—Generalized stratigraphic sections through the Tyers Group, showing the distribution of the dominant rock-types.

conglomerate in the river cliffs. This suggests that the conglomerate lenses out basinwards within a mile from its present base exposed along the Tyers River, whereas it persists along the strike at least 10 miles. Thus the conglomerate is wedge-shaped and conforms to a "fanglomerate" of Lawson (1925)—bodies characterized by a considerable persistence parallel to the edge of the basin but a rapid lensing basinwards. Such conglomerates are envisaged as marginal accumulations of detritus derived from sharply uplifted highlands.

The conglomerates are strongly cross-bedded. Some cross-bed units exceed 4 ft. but many are thinner. The cross-bedding is more apparent where sands are interbedded with the conglomerates. Exposures did not lend themselves to the study of the orientation of the cross-beds and only in two localities was it possible to compile enough measurements (see p. 193). Within the cross-bedded units the pebbles show a marked orientation (see p. 194).

The sandstones interbedded with the conglomerates are very similar to sandstones higher in the sequences. They are medium- to coarse-grained weathered creamy-buff sandstones containing essentially subangular to subrounded grains of quartz with occasional sedimentary rock fragments and weathered felspars. Detrital matrix is present but constitutes less than 8 per cent of the rock. This matrix consists essentially of finer-grained quartz and a little sericite. Where the rock is lithified it is cemented by authigenic overgrowths of secondary silica in the places where the quartz grains are in contact. Table 2 shows the micrometric analysis of such a sandstone from Anderson's Creek. Their good sorting attests to the strong winnowing action by currents before their ultimate deposition.

Noteworthy is the pitting of many of the conglomerate pebbles, particularly where the bulk of the conglomerate is made up of fine-grained greywacke in the localities where little or no matrix or cement is present. The best locality examined was on the east side of the Tyers River toward the top of the cliff section there exposed.

The term "pitted pebble" is generally applied to pebbles and cobbles which possess marked concavities apparently due in some way to contact with adjacent pebbles. The pitting in the pebbles of the Tyers Conglomerate is confined to the more disc-shaped pebbles of the softer rock types present. The concavities are smooth and may be up to 6 in. across and include almost the whole surface of a pebble. A group of typical pitted greywacke pebbles is illustrated in Pl. XXX, figs. 4 and 5.

Such phenomena have been attributed variously to mutual indentation by pressure, and solution induced by pressure at points of contact of the pebbles. Kuenen (1942), reviewing the literature on pitted pebbles, considered the idea of mutual indentation by pressure untenable. He states (p. 189), "The most obvious explanation, that of mutual indenture by pressure is easily withlain [*sic*]. Two pebbles squeezed in a vice will always fracture before denting each other. The material squeezed from an indenture should form a ridge around the pit, but normally the pebbles are smooth." Kuenen thus concludes that the only valid mechanism in the formation of pitted pebbles is by solution at points of pressure.

The pitting in pebbles from Tyers appears to have been brought about by mutual indentation in a way not covered by Kuenen's analogy. The flatter pebbles are structurally less able to withstand deformation than the more rounded pebbles. Thus a flattened pebble, supported underneath marginally by two rounded pebbles and centrally supporting another rounded pebble, in response to pressure on compaction

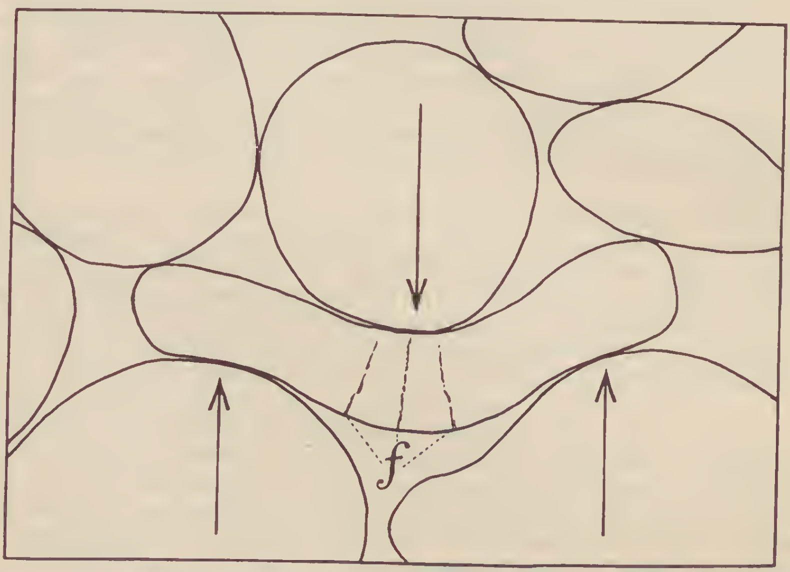

Fig. 3.—Schematic representation of the manner in which the "pitted" or "deformed" pebbles in the Tyers Conglomerate are produced, as a response to compaction. f = fissures.

tends to be deformed and wrap itself around the structurally stronger pebbles (Fig. 3). Moreover, all the pebbles of soft greywacke which show significant pitting also show concomitant fissuring along the zone of greatest deformation. It is concluded then that the pitting in these pebbles was caused by compaction. Such pebbles possibly should be described as "deformed pebbles" rather than "pitted pebbles".

(B) Greywackes

Immediately overlying the conglomerates and forming a significant part of the sequence is a group of massive sandstones which are here classified as greywackes. They are typically creamy to buff in colour although the finer-grained members particularly can be quite rich in carbonaceous material, when they are grey. They usually show cross-bedding, often on a very fine scale. Penecontemporaneous slumping is present toward their base along Rintoul's Creek. Their upper limit is difficult to define as they grade into well-sorted sandstones in which the detrital matrix has become subordinate. Their relative thickness in each of the stratigraphic sections can be seen in Fig. 2.

In thin section these Jurassic greywackes are medium to fine grained and poorly sorted, the grain sizes ranging from 0·5 mm. downwards. The grains are essentially angular to subangular quartz with minor amounts of more rounded fragments of fine-grained sedimentary rock. Felspar is virtually absent. Small bent flakes of detrital mica are present, together with occasional well-rounded zircons and tourmalines. The matrix, which may constitute up to 45 per cent of the rock, consists of finer quartz fragments and sericite stained by limonite. Fragments of coalified plant remains occur throughout the rock. Higher in the sequence there is less matrix in the greywackes. Clearly both in hand specimen and thin section these Jurassic greywackes match the Siluro-Devonian greywackes which outcrop to the north, and which, as has been pointed out, make up most of the cobbles of the conglomerates (cf. Pl. XXIX, figs. 2, 3). Micrometric analyses of both these rock types are shown in Table 2. They can be seen to be remarkably similar in mineral composition.

Interbedded with the greywackes are normal mudstones and shales. In places, as along the Tyers River, seams of black coal up to 3 in. thick are also present. Grits occur throughout the greywackes but are rarer towards the top. Some of these may show grading on a minor scale. In general they consist of subangular grains of vein quartz and sedimentary rock fragments up to 3 mm. in size, again set in a fine-grained matrix.

There is a virtual absence of labile constituents in the greywackes. Typical greywackes contain a considerable percentage of felspars and/or rock fragments. Fischer (1933) has suggested the term "quartz-wacke" for a greywacke in which the stable constituents make up more than 90 per cent of the rock. The "quartz-wacke" of Fischer is virtually synonymous with the "low-rank greywacke" of Krynine (1945) and the "subgreywacke" of Pettijohn (1949). The Siluro-Devonian greywackes, as well as these Jurassic greywackes conform to sandstones of this class. In the field these rocks can be readily distinguished from the normal Jurassic basin sandstones because of their colour. As has already been stated the normal felspathic sandstones are greeny-grey in colour when fresh, and weather to brown, the colour being due to the chloritic cement. The greywackes, on the other hand, are creamy-buff. The difference is due to the fact that the greywackes being packed tight with detrital material (or "paste") were impermeable to the solutions which deposited the chloritic cement in the "clean" felspathic sandstones. In the protoquartzites (see below) which overlie the greywackes, although the detrital matrix is subordinate, secondary silica has cemented much of the rock, preventing any influx of chlorite cement. Toward the top of these sandstones, however, they may take on the characteristic colour of the felspathic sandstones due to some introduced chlorite.

TABLE 2

Micrometric Analyses of Greywackes and Protoquartzites

Constituents	1	2	3	4
Quartz	51·7	49·4	68·5	69·8
Felspar	tr.	tr.	tr.	—
Sedimentary rock fragments	1·7	1·5	3·3	2·8
Secondary quartz and voids	—	2·5	13·9*	19·3
Minor detrital minerals†	3·4	2·2	0·5	tr.
Matrix	43·2	44·4	13·8	8·1

* Including introduced chlorite.
† Including carbonaceous material.

1. Siluro-Devonian greywacke, section cut from a pebble taken from the Tyers Conglomerate.
2. Typical Tyers Group greywacke, collected 470 ft. above the base of the section along Anderson's Creek.
3. Tyers Group protoquartzite, from 430 ft. above the base of the section along Tyers River.
4. Protoquartzite interbedded with conglomerate near base of section along Anderson's Creek.

(C) SANDSTONES (PROTOQUARTZITES)

The Jurassic greywackes pass up into well-sorted sandstones again showing marked cross-bedding. These may be creamy-buff through to greeny-brown in colour. Their relative thickness in each measured section is seen in Fig. 1.

In thin section they are seen to be medium-grained sandstones made up essentially of subangular to subrounded grains of quartz with very minor amounts of sedimentary rock particles and detrital matrix (Pl. XXIX, fig. 5). Authigenic overgrowths of quartz are present around many of the quartz grains, giving a false impression of angularity. The minor amounts of matrix present in the rock consist of fine quartz and sericite often stained by limonite, perhaps derived from the weathering of chlorite, traces of which are still present in the rock. A micrometric analysis of one such typical sandstone is given in Table 2.

Locally these sandstones may contain small pockets of fine conglomerates with grains up to 7 mm. across. They consist of well-rounded fragments of fine-grained sedimentary rock and occasional large angular grains of quartz set in a matrix of normal sandstone. One such conglomerate from the Tyers River is illustrated in Pl. XXX, fig. 4.

This sandstone agrees with Pettijohn's "protoquartzite", which is the more quartz-rich member of the lithic sandstone family. Here they represent "washed" greywackes formed by the elimination of the fine interstitial matrix which is so abundant in the greywackes. Such sandstones here were taken to reflect a period of decreased rate of subsidence of the basin, permitting more prolonged winnowing.

(D) FELSPATHIC SANDSTONES (ARKOSES)

At the top of the sections exposed from North Yallourn to Rintoul's Creek (Fig. 2) are felspathic sandstones proper of the Jurassic as described earlier in this paper. In the field they are dark in colour and are speckled brown to greenish-brown where they are fresher. Again they are cross-bedded but not as strongly as the sediments lower down in the sequence. These sandstones contain the characteristic andesite or andesitic tuff fragments together with felspars—the usual detrital components of the sandstones. Toward the top of the sequence they are indistinguishable from the normal arkoses from elsewhere in the Jurassic (see Table 1). These rocks are taken to represent material originally derived from the same general source as the great bulk of the Jurassic of Victoria, here brought in by current action and mixed with quartz derived from the highlands to the north. Cross-bedding studies (see later) suggest that high in the sequence the current direction became much more variable and was in part directed from the basin.

(E) Other Sediments

Normal mudstones and shales are interbedded with the sandstones. They weather to a brown colour but those rich in carbonaceous material remain a grey colour. Typically they are very fine silts with small angular fragments of quartz in a very fine matrix of sericite and clay. Shredded carbonized plant remains are abundant in most sections.

In places throughout the Tyers Group occur very thin seams of black bituminous coal usually only about two to three inches thick. These are apparently drift in origin as they are similar in occurrence to the other coals throughout the Jurassic sequence. They do not appear to be confined to any one horizon but are distributed sporadically through the sequence. The thickest coal seam within the Group outcrops in a small tributary of Anderson's Creek near the Anderson's Creek Fault. This seam is at least eight inches thick but is almost impossible to trace along the strike. The occurrence of the more important seams is shown in Fig. 2.

Intraformational conglomerates are present but not common in the sequence. They occur directly overlying the Tyers Conglomerate at North Yallourn, and are present at the top of the sections along the Tyers River and Anderson's Creek. Typically they consist of angular to subrounded fragments of mudstone set in a sandstone matrix. They apparently represent contemporaneous erosion of softer mudstone (Edwards and Baker, 1943).

Fossil Flora

No plant determinations have been recorded from the Tyers Group although Murray (1876, p. 141) notes the occurrence "of plant impressions similar to those in other portions of the mesozoic series" within the Tyers Conglomerate. Fragmentary plant remains and carbonized wood occur through much of the sequence but are much more common towards the top. *Taeniopteris spatulata* is by far the most abundant of the recognizable leaf impressions. The best-preserved plant remains in the sequence occur in grey silty greywackes along Rintoul's Creek about 450 ft. above the base of the section. Here the flora is represented by:

Taeniopteris spatulata
Taeniopteris crenata
Elatocladus mccoyi
Elatocladus cf. *conferata*
Sphenopteris (?) sp.

This flora is typical of that of the Victorian Jurassic sequence as a whole, regarded by Medwell (1954) as indicative of a Lower Jurassic age (with the exception of the Merino Group).

Source Rocks

The study of primary current structures within sediments has become standard practice in an analysis of current directions and possible source areas. Two such features were used in the Tyers Group—the first, cross-bedding; and the second, pebble orientation within the Tyers Conglomerate.

(A) Cross-bedding

McKee and Weir (1953) have attempted to classify cross-bedding on the basis of the arrangement of the cross-laminations. The cross-bedding within the Tyers Group conforms generally to their "simple" type (i.e. those in which the lower bounding surface of the sets is non-erosional) but "planar" types (those in which the lower surface is erosional) are not uncommon. It is doubtful whether classifications of this sort have any genetic significance and so their usefulness is open to question. The cross-bedded units are up to 4 ft. in thickness in the Tyers Conglomerate, but in the sandstones higher in the sequence they are of the order of 2 ft. or less.

Apart from the widespread use of cross-bedding orientation in locating possible source areas for cross-bedded strata (e.g. Potter and Siever, 1956) their study has been used for fixing the trend of ancient shore lines (Tanner, 1955).

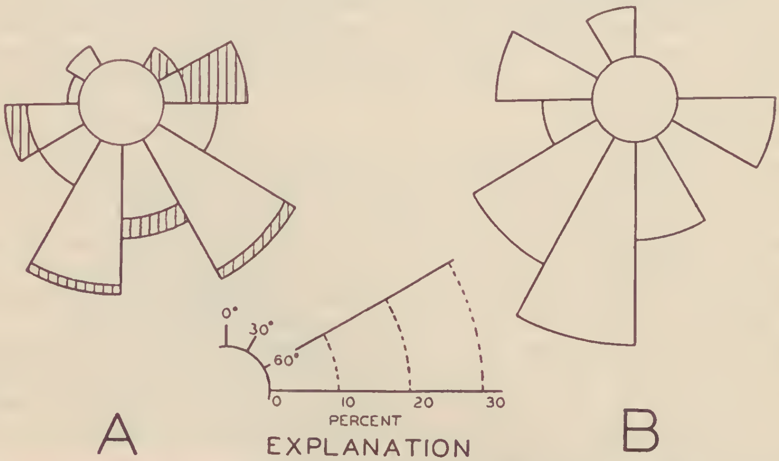

Fig. 4.—Cross-bedding azimuth distribution in the Tyers Group. A, 68 cross-bed measurements along Rintoul's Creek. The shaded area represents 14 of these measured above 750 ft. from the base of the section. These indicate a change in current direction to in part directed from the basin. B, 15 cross-bed measurements from Eaglehawk Creek.

In two places within the Tyers Group exposures were good enough to measure the orientation of a sufficient number of cross-beds. Even so, at one of these localities, only 15 cross-bed units were measured.

The procedure was to measure the strike and dip of the top of a cross-bed, either directly, or by calculating its true dip from two apparent dip readings. These were then adjusted for the tilt of the strata by appropriate rotation of the cross-bedded plane about the strike of the true bedding. The dip direction of each of the cross-bed surfaces was thus found and the data summarized in conventional "rose" diagrams.

Along Rintoul's Creek 68 cross-bedding measurements were made. Their orientation is shown in Fig. 4A. These have been arbitrarily divided into two groups, 54 measured in the lower 750 ft. of the section and 14 in the upper 600 ft. The lower 54 show a prevailing southerly dip of the cross-laminations and are taken to indicate that the sandstones and conglomerates in which they were measured were derived from the highlands to the north. The final 14 measured in the upper 600 ft. of the section show a marked increase in variability in cross-bed orientation. They are hardly sufficient in number to be really significant, but as they can be correlated with the entry of new detrital elements in the sandstones (andesite fragments and felspars), they are taken as indicative of a change in current direction to one in part directed from the basin bringing in the characteristic clastic debris of the Jurassic sandstones proper.

In the small section exposed along Eaglehawk Creek, 15 cross-bed measurements were made (Fig. 4B). Although again these are hardly enough to be significant they show a marked indication that these sediments were derived from the north.

(B) Conglomerate Fabric

A quantitative approach to the study of the orientation of pebbles in conglomerates and tills was introduced by Richter (1932). By studying the preferred shape orientation of the pebbles in a till, the plan of ice movements over a large area was reconstructed. Since then the study of pebble orientation in rudaceous rocks has become widespread. The technique consists of measuring the azimuth and dip of the long axes of a large sample of pebbles within a conglomerate bed. The observations are then usually represented on a stereographic diagram which may be contoured. Here the axes have been shown as a lower hemisphere plot and contoured with the aid of a "Schmidt" equi-area net.

Schlee (1957), working in recent fluvial gravels, showed that highly significant results may be obtained by plotting the orientation of as few as twenty pebbles by selecting pebbles of a characteristic shape, i.e. ones more likely to be oriented by current action during deposition. He plotted the orientation of the longest axis of "rod-shaped" pebbles and the shortest axis of "disc-shaped" pebbles on separate diagrams. For the placement of these axes see Krumbein, 1941. By eliminating the more spherical pebbles whose orientation may be almost at random to the main current direction the fabric of the gravel became much clearer.

Cailleux (1945) notes that the smallest pebbles in a gravel are oriented more by contact with larger pebbles than by current action. Consequently, in describing fabrics, he used pebbles larger than 4 cm. in length. White (1952) also found that in a bed of Keeweenawan conglomerate the smaller pebbles (less than 2 in. in length) were more randomly disposed than the larger pebbles.

For these reasons, in examining the fabric of the Tyers Conglomerate, only the orientation of the larger "rod-shaped" and "disc-shaped" pebbles was investigated. To avoid the obvious personal bias which could arise from such restricted sampling, the "rod-shaped" and "disc-shaped" pebbles were defined in terms of their axial lengths. Also only pebbles with their longest axis greater than 6 cm. were taken from the first locality studied, and those whose longest axis exceeded 10 cm. from the second locality. These figures approximate to the lower limit of the upper quartile of the size distribution in each case. The pebbles in the first locality were taken from a predetermined area of outcrop.

The "disc-shaped" pebbles were defined as those pebbles in which $c \leqslant \frac{1}{2} b$, while "rod-shaped" were those in which $c > \frac{1}{2} b$ and $a \geqslant b + c$. (a, b, and c are the axial dimensions of the pebbles in the longest, intermediate, and shortest directions—see Krumbein, 1941.) Although these definitions are slightly at variance with existing shape classifications of pebbles (Zingg, 1935; Harrison, 1957), they are much more simple to apply. No provision has been made for the "blades" of Zingg as no really bladed pebbles were present in the conglomerate. Most pebbles in the conglomerate fall within the above categories because of their low sphericity.

Because of the widespread siliceous cement, it was possible to study the fabric of the conglomerate in two localities only. The first was on the spur along which runs the Erica-Traralgon road. Here the conglomerate was weathered and the pebbles could be easily removed from the matrix. The orientation of 48 rod-shaped

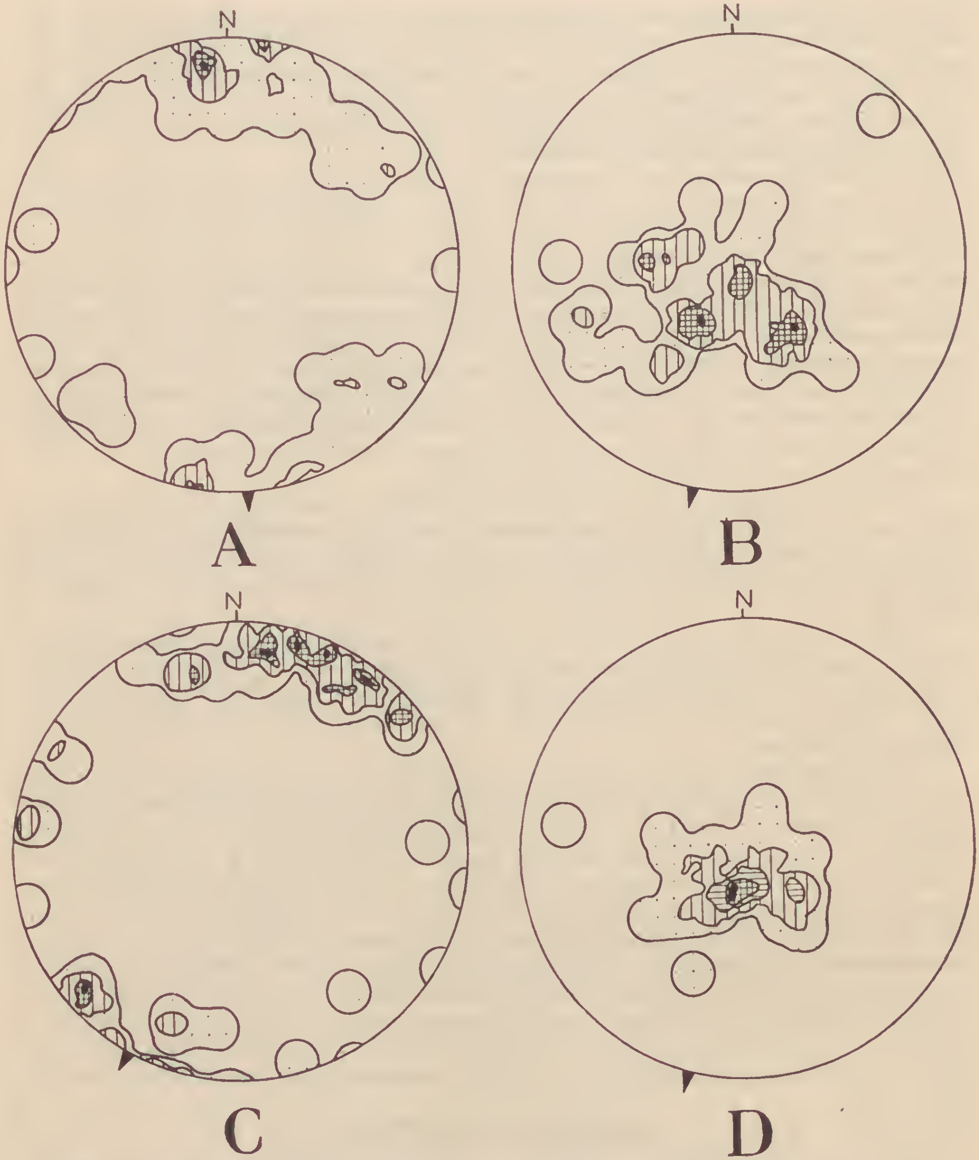

FIG. 5.—Contoured lower-hemisphere plots of the axes of pebbles within the Tyers Conglomerate. The diagrams have been appropriately tilted for the dip of the strata. A, *a* axes of 48 rod-shaped pebbles, contoured at the 2 per cent, 4 per cent, 6 per cent, 7 per cent levels. B, *c* axes of 41 disc-shaped pebbles from the same locality, contoured at the 1 per cent, 3 per cent, 5 per cent, 6 per cent levels. C, *a* axes of 35 rod-shaped pebbles, contoured at the 1 per cent, 2 per cent, 3 per cent, 4 per cent levels. D, *c* axes of 34 disc-shaped pebbles from the same locality contoured at the 2 per cent, 4 per cent, 6 per cent, 7 per cent, 8 per cent levels. The arrow-head on the periphery of each diagram gives the interpreted current direction.

and 41 disc-shaped pebbles was measured here. The results are summarized in Fig. 5A and B. The *a* axes of the rod-shaped pebbles show a well-developed 7 per cent maximum trending a few degrees west of north, and dipping northward at 12°, with a 5 per cent submaximum trending a few degrees east of north. The disc-shaped pebbles on the other hand show two 6 per cent maxima with the *c* axes dipping southward at an angle of about 65°.

When the measurements were being made it was suspected that pebbles from two cross-bedded units were being used, which is further borne out by the presence of the two maxima.

In the extensive cliff sections on the east side of the Tyers River it was apparent that the conglomerates were deposited in large-scale cross-beds. For this reason the orientation of pebbles was measured over a considerable area of outcrop. The orientations of 35 rod-shaped and 34 disc-shaped pebbles were measured. The results are summarized in Fig. 5C and D. The *a* axes of the rod-shaped pebbles here show a series of four maxima distributed in the north-east quadrant of the diagram and the pebbles tend to dip northwards. The disc-shaped pebbles have their *c* axes grouped around an 8 per cent maximum dipping steeply southwards. A 6 per cent submaximum nearby shows a similar disposition.

The most extensive study of the subject of pebble orientation within gravels has been made by Schlee (1957). For fluvial gravels he established that rod-shaped pebbles are oriented subparallel to the current direction and dip up-stream while the *c* axes of the disc-shaped pebbles tend to dip down-current at a high angle of about 70°.

Thus the data indicates that in the localities investigated the current direction was from the north. Fig. 5 shows the *a* axes of the rod-shaped pebbles to be dipping at an average of about 15° to the north, indicating that the current was from the north. This is again borne out by the inclination of the *c* axes which should be dipping down-current.

The conglomerates do not show such marked preferred orientation of the pebbles as the gravels investigated by Schlee. This is to be expected as they are not fluvial in origin. Another difference is that the Tyers Conglomerate has been compacted which in this case has deformed many of the pebbles and so altered their orientation.

Thus primary current features support the conclusion that the conglomerates, greywackes and sandstones of the Tyers Group were derived from the highlands to the north where the source rock was mainly greywacke. This conclusion is further substantiated by the matching of rock types within the Tyers Conglomerate and the mineralogical similarity between the sandstones of the Tyers Group and the Siluro-Devonian greywackes. The entry of the normal detrital elements characteristic of the bulk of the Jurassic sandstones is taken to represent material derived from elsewhere which has been brought in from the basin and mixed with sands from the local source.

Conditions of Sedimentation

The Tyers Conglomerate represents a marginal accumulation of coarse detritus derived from the highlands to the north which had apparently been strongly uplifted. The low sphericity of the pebbles, as well as the poor rounding of the harder rock fragments is taken to indicate short distance of transport before burial. In composition it is a typical polymictic conglomerate, composed essentially of rock types prone to weathering, and deposited under conditions of heavy sedimentation with strong current action (as shown by the large-scale cross-beds) in a rapidly sinking basin.

The greywackes above the conglomerates also indicate conditions of rapid sedimentation. Greywackes are typically geosynclinal sediments showing graded bedding and strongly characteristic of this tectonic environment. It is noteworthy that here they are cross-bedded. They are present in this limnic environment apparently because of two reasons—first, because greywackes constitute their source (they could well be regarded as second-cycle greywackes), and, secondly, because rapid sedimentation and burial accompanied their deposition. This rapid burial is further indicated by the fact that the best-preserved plant remains in the series occur within these sediments. That the current action was not so strong as in the conglomerates is indicated by the smaller cross-bedded units.

The sandstones (protoquartzites) above the greywackes indicate an approach to the stable conditions of sedimentation under which the remainder of the Tyers Group was deposited. They in fact represent "washed" greywackes in which the detrital matrix has been removed by current action. Overall these well-sorted sediments indicate very mild subsidence during accumulation and considerable transport and winnowing action before final consolidation. It was under such conditions that the rest of the Jurassic sequence of Victoria was deposited. Burial was, however, fairly rapid in the normal felspathic sandstones, as the felspars in this rock are remarkably fresh.

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